natural agencies which tend to remove nitrogen from the soil, had undisputed possession of the field. When the manuring was discontinued, the losses of nitrogen, according to Dehérain's results, sank very materially, though still remaining considerable.

From the combined results of both these investigations, it would appear that we may fairly conclude, that, under ordinary conditions of tillage, there is considerable loss of nitrogen from the soil. Lawes, Gilbert, and Warington's experiments show that much nitrogen may escape in the drainage; and, according to their calculations, more nitrogen was removed from six out of thirteen of their experimental plots in crop and drainage, during thirty years, than was supplied in the manure. From Dehérain's experiments we learn that a soil under constant tillage may grow poorer in nitrogen in spite of heavy manuring. In fact, of all the elements of the soil which are required for plant-growth, nitrogen is one of the most mobile. The soil, it is true, has the power of fixing ammonia in insoluble combinations; but both ammonia and organic nitrogen are constantly being converted into nitric acid in every fertile soil, and this compound the soil has no power to retain. Under natural conditions, when the soil is thickly covered with vegetation, this nitric acid is assimilated by the roots as rapidly as it is formed, while the compact state of the soil hinders access of oxygen to the deeper layers, and thus moderates nitrification. This action of plant-roots in arresting nitrates on their way to the lower strata of the soil is shown very plainly in Lawes, Gilbert, and Warington's experiments already cited. While the land carried a crop of wheat, the drain-water contained little or no nitrates, except when an excess of nitrogen had been given in the manure; but as soon as the crop was removed, nitrates made their appearance in the drain-water.

But an untilled soil is not only protected against losses of nitrogen: it is also in condition to retain the nitrogen brought to it in rain, snow, etc. This comes partly in the form of ammonia, which is fixed by the soil, and partly in the form of nitric acid, which is fixed by the vegetation. In this way a soil carrying permanent vegetation may be continually gaining nitrogen. This is indicated by Dehérain's results on the esparcette plots, and, aside from them, is sufficiently evident from the facts, that at some period of the world's history all its nitrogen must have existed in the free state, and that, so far as we know, the combined nitrogen of atmospheric precipitates is the sole natural source of nitrogen to the soil.

Tillage alters this state of things very materially. By breaking up and mellowing the soil, it facilitates the access of oxygen, and increases the rapidity of nitrification. At the same time, the natural vegetation is replaced by one occupying in many cases but a part of the ground, and occupying it for but a portion of the year. Add to this that by diminishing the amount of vegetation we diminish the evaporation of water, and thus leave the soil moister, and at the same time expose it more fully to the sun's rays, thus rendering it warmer, both of which conditions favor nitrification, and we see that cultivation both increases the flux of nitrogen in the soil, and decreases the means of utilizing it.

The clear recognition of this state of things brings with it the suggestion of at least a partial remedy, which is to keep the soil occupied as fully and as long as possible with growing vegetation. The roots of the living plant lend to the soil an absorptive power for nitrogen compounds, similar to that which it has of itself for other elements of plant-food, and enable it to store up these compounds against future needs. To prevent a loss of nitrogen, we must make use of this power as fully as possible, both in the system of cultivation adopted, and in other ways. After taking off a crop in the early fall, instead of leaving the land bare, let it be sown with some quick-growing crop, e.g., rye, which shall serve solely to store up the nitrogen which would otherwise be lost. In the spring this crop is ploughed under, and furnishes nourishment for the succeeding crop. Such a plan has been adopted here and there with advantage. Its general use would turn largely, of course, on the question of expense. On a virgin soil containing already large reserves of nitrogen, no appreciable benefit might result from it, though even there the *preservation* of the present fertility is worth striving for. But between this condition and the state of relative exhaustion to which the soil of our older states has been reduced, there must be a point where saving nitrogen in this way would be of immediate as well as prospective benefit. The exact methods of applying the principle involved to particular cases it is not the province of this article to discuss. The principle itself, however, is very simple. Keep growing roots present in the soil as long and as extensively as possible to seize upon the nitrogen (and other elements as well) which will otherwise be washed out of the soil, and to store it up in insoluble forms, ready for the needs of future crops.

H. P. ARMSBY.

THE LIFE OF HAMILTON.

Life of Sir William Rowan Hamilton, Knt., LL.D., D.C.L., M.R.I.A., Andrews professor of astronomy in the University of Dublin, and royal astronomer of Ireland, etc.: including selections from his poems, correspondence, and miscellaneous writings. By ROBERT PERCEVAL GRAVES, M.A., sub-dean of the Chapel royal, Dublin. Vol. i. London, *Longmans, Green, & Co.*, 1882. 20+698 p. 8°.

THIS volume, which forms one of the latest issues of the Dublin university press series, has been prepared partly through the assistance furnished by the Board of Trinity college, and published by the provost and senior fellows. Mr. Graves had at first, however, undertaken the biography of Hamilton on his own responsibility, and unassisted in the labor which it involved; and we ought not to pass unremarked his especial fitness for the performance of this arduous task. In the first place, he was unconnected with Hamilton by

any tie of kindred. Both had experienced unbroken friendship from early youth. Hamilton, in his will, had nominated Mr. Graves as his literary executor; and the sons of Hamilton asked him to undertake the task, seconded by the approval of several of the most influential friends of the great mathematician. And, while Mr. Graves has to confess himself to be no mathematician, he combined — what was of greater import — the requisite amount of personal knowledge with the appropriate scientific attainments and freedom from incompatible engagements. In his preface, the author very gracefully says, by way of allusion to his self-distrust in assuming the control of Hamilton's voluminous papers and correspondence, "I gave a reluctant consent, wishing that the memory of my friend had been more fortunate, but at the same time conscious that by me would be devoted to it the warmth of honest affection and admiration, and the desire to be just and truthful."

In recording the successive mathematical discoveries of Hamilton, Mr. Graves does not attempt accurately to appreciate their importance, or to give them their exact place in connection with precedent or subsequent discovery. He has taken pains to secure that the mathematical statements in his work are correct, giving them generally in the *ipsissima verba* of Hamilton himself, and, where in doubt, consulting friends of competent authority. This course begets a desirable confidence in the accuracy of the entire work, — which is, however, taken as a whole, almost purely a literary biography. It is not so much to the credit of Mr. Graves as may at first seem probable, that he leaves the letters of Hamilton almost unaided to tell the story of his life. The contributions from the author's pen are very largely of the nature of disconnected comment, usually upon a subjoined letter: in fact, there is nothing approaching a continuous analysis of the life or work or character of Hamilton, such as we may hope to see in a subsequent volume, and which Mr. Graves, from his evidently keen insight, and thorough acquaintance with the subject of his biography, is of all persons most fully qualified to write. Nor could the book have been otherwise than improved, had he drawn very largely from his own association and personal recollection of Hamilton in the interest of those who never knew him.

The name of William Hamilton has conferred a threefold distinction upon the kingdoms of Great Britain. An early article on the subject of this biography reminds its readers that each isle has its Sir William Hamilton. The Englishman was noted for his patronage of art, the Scotchman was among the first in philosophy, and the Irishman was among the first in mathematics. And the promise of greatness the young Irishman gave at that early day failed in no sense of entire fulfilment in the development of mature years. Of the three Hamiltons, William Rowan was easily the chief. We recall in this connection what some of his most distinguished contemporaries have said of him. The celebrated Dr. Brinkley, astronomer royal of Ireland (later Bishop of Cloyne, and whose successor in the former office the youthful Hamilton was so soon to be), said of him at the age of eighteen, "This young man, I do not say *will be*, but *is*, the first mathematician of his age." The brilliant and learned Professor Sedgwick, referring publicly to Hamilton in 1833, spoke of him as "a man who possessed within himself powers and talents perhaps never before combined within one philosophical character." Hamilton was born in Dublin, Aug. 4, 1805, and died in the same place, from an attack of gout, Sept. 2, 1865, being then royal astronomer of Ireland. His early life is the story of alarming precocity, not of invention, but of acquisition. Nothing could have seemed more certain to those who knew the boy of half a score than that middle life would easily insure him rank as the chief of linguists. At five he was able to read and translate Latin, Greek, and Hebrew; at eight, he knew Italian and French; and before the age of ten his father wrote of him, "His thirst for the oriental languages is unabated. He is now master of most, indeed of all except the minor and comparatively provincial ones. The Hebrew, Persian, and Arabic are about to be confirmed by the superior and intimate acquaintance with the Sanskrit, in which he is already a proficient. The Chaldee and Syriac he is grounded in, and the Hindoostanee, Malay, Mahratta, Bengali, and others. He is about to commence the Chinese." One of Hamilton's earliest productive efforts was the preparation of a little manuscript book of thirty pages, formally entitled 'A Syriac grammar, in Syriac letters and characters,' etc. (p. 51). He was not as yet twelve years of age; and before another year had passed, his works included (these are the titles given by the boy himself) 'A grammar of the Sanskrit language,' 'An Arabic praxis,' 'An analysis of a passage in Syriac,' and 'A compendious treatise of algebra,' which latter proceeds as far as quadratic equations. Up to this point, Hamilton seems to have had no marked disposition toward scien-

tific studies. He had been fascinated by telescopic views of the planets, and had visited the Royal observatory at Dunsink. Unquestionably one of the most important events in his early career was the meeting of Zerah Colburn. The two had engaged in trials of arithmetical skill when the former was only twelve; but two years later they re-met, Hamilton being "not so much the antagonist as the critic and the investigator of the methods of the gifted computist." That it would be difficult to over-estimate the significance of this occurrence is evident from a letter by Hamilton to his cousin Arthur, in 1822, wherein he says (p. 111), —

"I was amused this morning, looking back on the eagerness with which I began different branches of the mathematics, and how I always thought my present pursuit the *most* interesting. I believe it was seeing Zerah Colburn that first gave me an interest in those things. For a long time afterwards I liked to perform long operations in arithmetic in my mind; extracting the square and cube root, and everything that related to the properties of numbers. It is now a good while since I began Euclid. Do you remember when I used to go to breakfast with you, and we read two or three propositions together every morning? I was then so fond of it, that, when my uncle wished me to learn algebra, he said he was afraid I would not like its uphill work, after the smooth and easy path of geometry. However, I became equally fond of algebra, though I never mastered some parts of the science. Indeed, the resources of algebra have probably not been yet exhausted."

The practical bent of his young mind in scientific matters is interestingly shown by his invention of a telegraphic signal-code, which, for a youth of fifteen, is not a little remarkable. The letters of the alphabet were first arranged in the following scheme (p. 88) : —

	1	2	3	4	5
1	A	B	C	D	F
2	G	E	H	J	K
3	L	M	I	N	P
4	Q	R	S	O	T
5	V	X	Y	Z	U

Twice U = W

Then five readily distinguishable positions of the arms were chosen. Each letter, thus, would be indicated, after the manner of a double-entry table, by its position at the intersection of a horizontal and a vertical column; and the numbers of these intersecting columns, transmitted from one station to the other by the pre-arranged signals, would thus spell out any desired message. It will be observed that the duplication of any given position of the arms always indicates a vowel. This device for communication at a distance was for a time practically employed by Hamilton and a playmate of his, each being provided with a telescope, so that he could readily discern the successive positions of the arms of the other. His devotion to astronomy had by this time taken firm hold; and Hamilton realized this so fully himself, that he forcibly made in his studies a 'sudden transition to natural philosophy,' excusing himself therefor to his friends by explaining that the "intention was to prevent my giving up too much time to astronomy by diverting my thoughts to another channel: '*atqui emovit veterem mire morbus novus*,' for I am now as deeply engaged in the study of pendulums." In a short paper, at the age of sixteen, he brings science to the assistance of the classics, finding astronomical calculation to help in the decision of a moot-point in the chronology of the Aeneid.

It is most interesting to follow the growth of Hamilton's young mind as his fondness for the mathematics increased, and his devotion to the classics waned. His pre-collegiate letters abound in passages evincing the radical change which was going on, and the solid permanency with which his new favorites had taken possession. A passage from a letter to his sister Eliza, shortly after his entering Trinity college, is cited here as a vigorous illustration of this: —

"One thing only have I to regret in the direction of my studies, that they should be diverted — or rather, rudely forced — by the college course from their natural bent and favorite channel. That bent, you know, is science — science in its most exalted heights, in its most secret recesses. It has so captivated me — so seized on, I may say, my affections — that my attention to classical studies is an effort, and an irksome one."

Immediately on abandoning his absorbing interest in the classics, his work of original research in mathematical optics began. Mr. Graves quotes the title of an "Essay on equations representing systems of right lines in a given plane," etc., — a paper of twenty-one folio pages, to which Hamilton himself had appended the following note: "(This curious old paper, found by me to-day in settling my study, must have been written at least as early as 1822. It contains the germ of my investigations respecting Systems of rays, begun in 1823. W. R. H., February 27, 1834.)"

Hamilton's college career was a most brilliant one. During no small portion of his leisure, he was at work developing the germs of the above-named investigation, which, in the spring of 1827, was presented to the Royal Irish academy, having been expanded into 'A theory of systems of rays.' The first part was published the following year in the fifteenth volume of the academy's transactions. His collegiate course had not been completed, when, less than twenty-two years of age, he was unanimously elected Andrews professor of astronomy in the University of Dublin, and royal astronomer of Ireland, — an extraordinary preference for an undergraduate, who had for competitors men of high standing and eminence in two universities. His appointment under these circumstances involved another exceptional event: by the donor's direction, the professor of astronomy is one of the examiners for Bishop Law's prize, which is yearly bestowed upon the best answerer in the higher mathematics among candidates of junior bachelor standing. The new occupant of the chair of astronomy was, within a few days of his appointment, called upon to take his part in the examination; an undergraduate thus officially examining graduates in the highest branches of mathematics.

In the following autumn, Hamilton met the poet Wordsworth. Their correspondence of years, in terms of close intimacy, is very fully given by Mr. Graves, and forms the richest extra-scientific contribution to this biography. We may appropriately allude, in this connection, to Hamilton's poems, with which a very considerable fraction of this large volume is filled. Wordsworth criticised these effusions very freely, and not a few of them are certainly unworthy of Hamilton's better moments. The subjects chosen for versification, however, show an instinctive correctness in the choice of objects and impressions, which, treated by a poet, would be poetry, but, as dealt with by Hamilton, are in general merely healthy ideas plainly and unpoetically expressed in rhyme or verse. Another friendship of Hamilton's we should not omit to mention, — that of the philosopher Coleridge, whom he met in London shortly before the former's death. Their spirited metaphysical correspondence is a very agreeable feature of the present work.

To the wisdom of the same board of electors which, without doubt, saved Hamilton to science from the church (for he had at one time serious intention of entering that body, and was more than once offered ordination), are due the thanks of mathematicians perpetually for their prompt recognition of the true sphere of his intellectual activity. The duties of his university chair, as director of the observatory, were in large part uncongenial to him, and his brief career as a practical astronomer was not a successful one. His tastes being almost entirely in the direction of mathematical research, it was ultimately fortunate, that, from the commencement of his practice as an observer, his vigor of constitution was seriously impaired. Near the close of 1830 he writes to Sir John Herschel, "I cannot say much for my diligence in observing, but perhaps may have a better account to give of this department after some time; though among other temptations to indolence, I have that of always suffering in health when I attempt night work in the transit-room." He had constant cold in the head and chest, and was much of his time confined to the house. The proposal was soon made that he should change the professorship of astronomy for that of mathematics; and consulting with his friend, the late Dr. Robinson of Armagh, the latter replied. —

> "Your course appears to me so clear that there can be no hesitation. As a mathematician you will probably have no equal in Britain, as an astronomer some superiors; for you certainly have not the *practical* enthusiasm which is essential to make one sustain the uniform progress of observing. I was well aware that you are not very fond of observing; but you know you have that in common with Encke (who *hates* it), Airy, and Pond (now never observing)."

In November, 1831, the university board passed a resolution which more than doubled Hamilton's salary, and completely defined his future relations to the university; giving him entire liberty to pursue, as a first object, his mathematical researches, and thus assuming the responsibility of his continuing as a mathematician rather than an astronomer.

Hamilton's friends were not slow to do themselves the honor of proposing his membership of scientific bodies. Through Sir John Herschel he became a member of the Royal astronomical society at the age of twenty-two; three years later he was introduced to the British association for the advancement of science; Lubbock was ready to insure his election to the Royal society (of which, however, he never became a fellow); and in a letter, in 1832, to his intimate companion, Aubrey de Vere, he says, (p. 610), "A hand has lately been stretched forth to me across the Atlantic; a diploma having been sent, with great pomp of broad-seal, and so forth, to tell me that I have been

elected fellow of the American academy of arts and sciences —

"Ueber länder und meer reichen sich beide die hand."

A picture of curious interest may be drawn from Mr. Graves's occasional touches, portraying Hamilton as a speaker and lecturer. He "had two voices — one deep, rich, sonorous, rhythmical, and solemn, which flowed forth when he delivered a prelection or a speech, or recited poetry; the other soaring acutely into high regions, when he burst into an explanation, or gave vent to some ebullition of good spirits or cheerful comment." At the meeting of the British association in 1832, at Oxford, his speech returning thanks on behalf of the Royal Irish academy contained "a graceful expression of the feelings stirred in him by his peculiar position as the solitary and youthful representative of Ireland on the occasion." Babbage told him, in congratulation, that "an astronomer had no business to be able to speak so well." We have space for only a word from Mr. Graves's charming sketch of Hamilton as a lecturer (pp. 497–498): —

"When he spoke . . . it was plain to see that he was absorbed by a reverential consideration of the grandeur of astronomy. . . . As he poured out in his sonorous tones his thoughts thus blending poetry and science, he appeared . . . absorbed in awed and delighted contemplation of the truths he had the solemn privilege of enouncing; there was no apparent consciousness of his own personality, he was a worshipper revealing the perfections of the object of his worship; and towards the youthful audience who surrounded him he took the attitude not so much of a superior authority and a teacher as of a worshipper desirous that other intelligent spirits should take fire from the flame of his devotion. . . . In these introductory lectures he was wont to indulge himself in refined and eloquent disquisition, in poetic language, quotation and allusion, in tracing the history of the development of the science, and in marking out the achievements of its great promoters. . . . The subsequent lectures of the course were altogether different in style, being rigorously mathematical and demonstrative. . . . They were delivered with an eager simplicity, in a voice often breaking into a high key, strangely contrasting with the deep roll of his oratorical effusions."

One of Hamilton's grandest achievements was the theoretical discovery of conical refraction; and in the popular history of physics he is chiefly known by this. Its prompt confirmation by Dr. Lloyd, in the laboratory of the Dublin university, tended strongly to heighten the dignity of the discovery. It was characterized in terms of most extravagant applause by the greatest physicists of that day. But Hamilton himself, with the unaffected simplicity of true genius, describes it to Coleridge as a 'subordinate and secondary result.' The discovery had no parallel in the history of exact science; and, as Mr. Graves appropriately remarks, it is only "to be classed with that prediction of the existence of the planet Neptune which has immortalized the names of Adams and Le Verrier."

Nothing, perhaps, will better exemplify Hamilton's rare elevation of character than the following brief words of his biographer: —

"It is to Hamilton's honour that the impression he made upon young men, his coevals and his juniors, was such as to create in them the warmest affection, admiration, and respect. This arose from his unaffected humility and his cheerful communicativeness, combined with his power to solve most difficulties admitting of solution, his frankness in confessing ignorance, his reverential and profound treatment of all great questions."

In so far as it is possible to know the distinguished Irishman from his letters, — and they are presented in the fullest profusion, — the most commanding feature of his character is the absolute absence of every thing akin to meagreness of build: in other words, a thorough and genuine nobility. Repeated illustrations of this might be cited from his correspondence; and it is the most conspicuous element of the admirable frontispiece which has been autotyped from a photograph by Chancellor, Dublin, of a miniature bust executed by Terence Farrell in 1833. We should like to express the hope, that, before the conclusion of his task, Mr. Graves will present a print from the other bust of Hamilton, executed, at the request of Lord Dunraven, by the Dublin sculptor, Kirk; in preparation for which a cast was taken from the head, and which thus, as faithfully representing his cranial development, can hardly fail to possess a permanent value.

It is most irksome to be forced from the contemplation of this great genius; for, with this initial volume of his biography, we have to leave him at the age of twenty-seven, and almost in entire anticipation of his characteristic scientific life. His unique researches in the highest fields of mathematical investigation, his great contributions to the science of dynamics, were yet unmade; and the calculus of quaternions, if at all thought of, had no more taken shape than the vague indefiniteness of a dream. If Mr. Graves has disappointed any of his readers in the execution of his task, they must be few, and among those who were so favored as to have enjoyed the intimate acquaintance of the great mathematician. The successive instalments of this exceedingly valuable biography cannot fail to be watched for with eagerness, and welcomed with enthusiasm, by all whose interests embrace the history and development of the exact sciences.